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IMPULSE RADIO UWB PRINCIPLES AND REGULATION

FLAVORS OF IMPULSE RADIO UWB

The physical layer of UWB is available in two flavors in the upcoming IEEE 802.15.4z standard [B1]: a) low (L) rate (R) pulse (P) repetition frequency, and b) high (H) rate (R) pulse (P) repetition frequency.

The envelope of the RF UWB pulses is depicted in Figure 1. LRP basically sends pulses with a lower repetition rate than HRP to allow high instantaneous peak power, a reduced number of pulses and a direct image of the channel impulse response as shown in Figure 1. This is beneficial for all key performance indicators listed in Table 1.

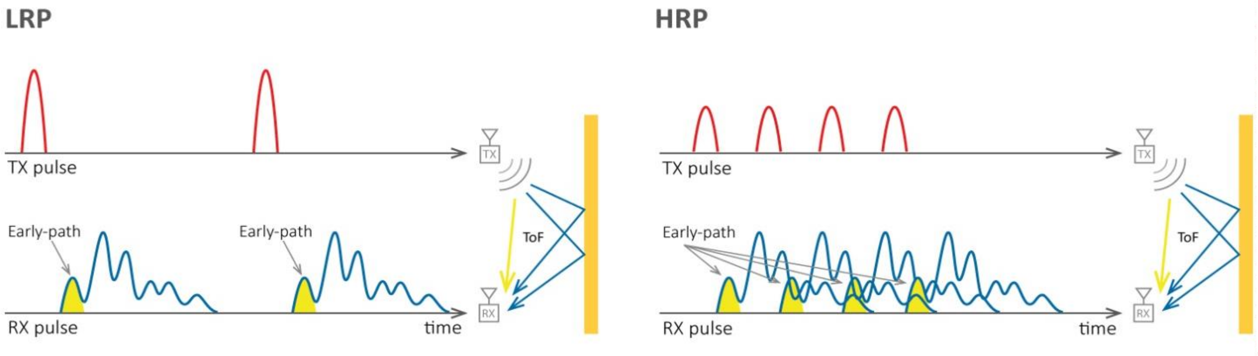

Figure 1: *Main principle of LRP and HRP UWB transmission and reception. LRP sends pulses with a lower repetition rate than HRP to allow high instantaneous peak power, a reduced number of pulses and a direct image of the channel impulse response.*

Note that in all comparisons we assume that both LRP and HRP pulses use the same pulse duration t_p, i.e., same pulse bandwidth in frequency domain.

FREQUENCY SPECTRUM USAGE

UWB transmission is strictly limited by regulation. **There are two rules:**

The first rule dictates the maximum mean Power Spectral Density (PSD), i.e., the radiated power within a given bandwidth when averaged over 1 ms:

max. mean *PSD = -41.3 dBm / MHz (74 nW per MHz)*

The second rule imposes a limit on how strong a single pulse can be transmitted. It basically limits the power of the UWB signal to 0 dBm when passing it through a filter of a bandwidth of 50 MHz:

max. peak *PSD = 0 dBm / 50 MHz*

From the first rule, the power per MHz is 13’500 times less than typical short range radio devices such as Bluetooth or Zigbee which transmit at 1mW per MHz. UWB first overcomes this situation by using a very large bandwidth. Assuming a pulse occupying a bandwidth of 500 MHz (pulse duration t_p = 2 ns), we obtain a maximum average power of 37 µW (-14.3 dBm) by multiplying the 500 MHz of bandwidth with the maximum spectral density of 74 nW/MHz.

But, 37 µW is more than one order of magnitude lower than what other short range radio technologies transmit.

How does UWB with significantly less transmit power achieve comparable communication range to other short range radio technologies?

The first rule also states that the maximum mean PSD has to be averaged over at most 1 ms. This means that during that millisecond, we could theoretically send just one very strong pulse with a maximum full band peak power depending on the pulse duration t_p. Taking the numerical case above with t_p = 2 ns and P_{TX} = -14.3 dBm yields an instantaneous full band peak power of +42.7 dBm (18 W) as shown in Figure 2.

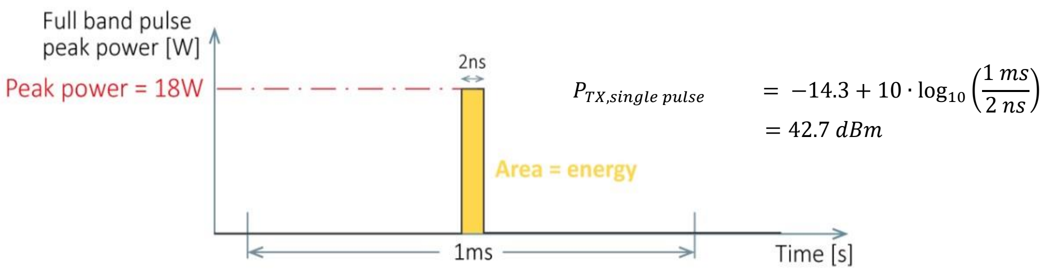

***Figure 2**: Single pulse transmission in 1 millisecond period containing the maximum 37 µW of transmitted power results in a 2 ns pulse peak power of approximately 18 W.*

The second rule however limits the instantaneous pulse peak power to a value that shall not exceed 0 dBm when passing the signal through a 50 MHz bandwidth filter (i.e., 10% of the energy of the original 500 MHz wide signal). This translates into a full band signal peak power of +20 dBm [B2] (which is 22.7 dB lower than when only the first rule is applied). Therefore, to comply with both rules and maximize the transmitted energy per pulse, we can transmit **186** (= $10^{(-22.7/10)}$) **pulses** of +20 dBm (500 MHz bandwidth). Therefore, the mean pulse repetition rate of transmission becomes 1 ms /186 pulses = 5.3 µs [B2].

This trade-off of instantaneous peak power against average power enables UWB to achieve high SNR and a communication range comparable to other short range radio technologies.

Worldwide UWB regulations strictly limit the amount of pulse energy (yellow area in figures) that can be sent during 1 ms. Sending stronger pulses is beneficial for the communication range (link budget), but for higher data rates, more pulses might be required and these have to be sent with a lower energy per pulse which will drastically reduce the range of a higher data rate UWB link.

Depending on the modes in the UWB standard and implementation trade-offs, the number of pulses may be higher and naturally the pulse peak power will be reduced.

As a point of comparison, short range radio technologies such as Bluetooth and WiFi do not have a limitation in the transmitted RF energy. They can operate indefinitely only with a power limitation and therefore provide continuous high data rate communication.

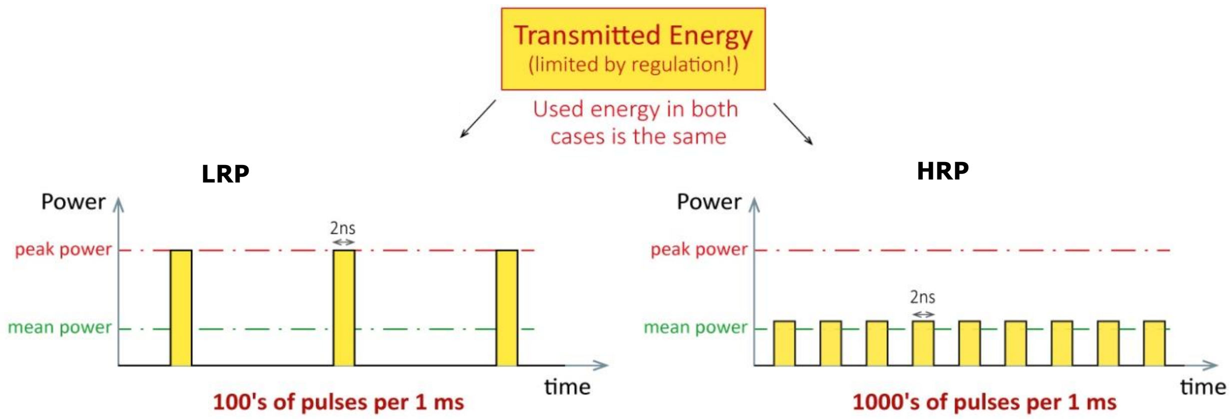

Figure 3: *The number of transmitted pulses in HRP UWB is more than an order of magnitude higher than in LRP UWB, but the individual pulse energy is proportionally weaker. Both LRP and HRP use exactly the same transmitted RF energy.*

Increasing the number of pulses sent in 1 ms leads to a reduction of the pulse peak power. This introduces additional constraints on the receiver without increasing the UWB performance. The reason is that the transmitted RF energy has to remain the same!

IMPORTANT

- For both LRP and HRP, the **maximum transmitted energy is the same** and fixed by the first UWB rule to 37 nJ for a 500 MHz bandwidth.

IMPORTANT

- One can choose to send **many weak pulses (HRP principle)** or **less but stronger pulses (LRP principle)** to better exploit the second UWB rule.

- The number of transmitted pulses in HRP UWB is more than an order of magnitude higher than in LRP UWB, but the individual pulse energy is proportionally weaker.

OUTLINE NEXT:

In Table 1 we provide an overview comparing the two UWB flavors to the popular BLE short range technology in terms of key performance indicators (KPI) including secure ranging guarantees, current consumption, energy per ranging, early path detection capability, silicon cost, etc. While both UWB flavors provide for precise distance and angle estimations as opposed to BLE, the difference in the **pulse repetition rate** and **frequency spectrum usage** has a dramatic impact on the KPIs even between the two UWB flavors. More details on this will follow in the next articles:

Article 2: Principles and implications on ranging with LRP and HRP UWB (1)
Article 3: Principles and implications on ranging with LRP and HRP UWB (2)
Article 4: Principles of secure ranging with LRP UWB
Article 5: Summary and practical use case considerations

Table 1: High-level comparison of key performance indicators of IEEE 802.15.4z LRP/HRP and BLE

Key Performance Indicator	IEEE 802.15.4z LRP	IEEE 802.15.4z HRP	BLE
Distance precision and accuracy	High	High	Low
Angle of Arrival accuracy	High	High	Medium
Comm. range in dense multipath	High	High	Medium
Secure ranging	Yes (provable)	Proprietary (unknown)	No
Current consumption	Low	Very high	Low
Energy consumption per ranging	Low	High	Low
Wake-up radio capability	Yes	No	Yes
First path detection dynamic range	High	Medium	Poor
Cost of ownership	Low	Very high	Lower
Distance measurement latency	Fast	Medium	Slow

REFERENCES

[B1] IEEE P802.15.4z, IEEE Draft Standard for Low-Rate Wireless Networks Amendment: Enhanced High Rate Pulse (HRP) and Low Rate Pulse (LRP) Ultra Wide-Band (UWB) Physical Layers (PHYs) and Associated Ranging Techniques, URL: https://www.techstreet.com/ieee/standards/ieee-p802-15-4z?gateway_code=ieee&vendor_id=7291&product_id=2087572

[B2] R. J. Fontana and E. A. Richley, "Observations on Low Data Rate, Short Pulse UWB Systems," *2007 IEEE International Conference on Ultra-Wideband*, Singapore, 2007, pp. 334-338.
URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4380965&isnumber=4380907